REPORT R-346 APRIL, 1967

CSL COORDINATED SCIENCE LABORATORY

THE PLASMA DISPLAY PANEL - A NEW DEVICE FOR INFORMATION DISPLAY & STORAGE

B.M. ARORA
D.L. BITZER
H.G. SLOTTOW
R.H. WILLSON

UNIVERSITY OF ILLINOIS - URBANA, ILLINOIS

This work was supported in part by the Joint Services Electronics Program (U. S. Army, U. S. Navy, and U. S. Air Force) under Contract No. DA-28-043-AMC-00073(E); in part by the Advanced Research Projects Agency through the Office of Naval Research, Contract Nonr-3895(08); and in part by the Syracuse University Research Corporation, Contract SURC 66124.

THE PLASMA DISPLAY PANEL--A NEW DEVICE FOR* INFORMATION DISPLAY AND STORAGE

B. M. Arora
D. L. Bitzer
H. G. Slottow
R. H. Willson

Abstract

The Plasma Display Panel, invented at the University of Illinois, is a rectangular array of bistable gas discharge cells which are insulated from exciting electrodes by thin glass panels. Combining the properties of memory, display, and high brightness in a simple structure it is an effective, economical device for information display.

---

*To be presented at the Eighth National Symposium of the Society for Information Display, San Francisco, May 24-26, 1967.

1. INTRODUCTION

It is unfortunate that the versatility of computer displays is not matched by their economy. This is particularly true for the large multiple access computer systems whose very development could be impeded by this disparity. It was, in fact, the needs of one potentially large system, the PLATO teaching system at the University of Illinois, that stimulated research that, in turn, lead to the conception of the Plasma Display Panel.[1,2,3] This new device combines the properties of memory, display, and high brightness in a simple structure that should be inexpensive to fabricate. Equally important is the fact that, since its images need no regeneration, it can be linked to a computer through inexpensive voice grade lines. In this paper we discuss the principles of this display.

2. DESCRIPTION

The display panel is constructed of three sheets of thin flat glass as shown in the exploded view of Figure 1 and in the section view of Figure 2. The center sheet is drilled or etched with a rectangular array of holes. On each of the outer surfaces of the other two sheets a grid of transparent electrodes is vapor deposited. The sheets are then assembled with the grids orthogonal to one another, and with a hole at each intersection. Each discharge cell is thus a small cylinder, excited by electrodes that are insulated from the cell by the outer glass panels.

The panel is sealed on three sides, and on the fourth side it is connected to Pyrex tubing which is in turn connected to a vacuum system. The panel is evacuated and filled with the working gas. The glass sheets are

typically .006 inch thick and the distance between the adjacent cells is .025 inch. The cell density is therefore 1600 cells/inch^2.

Like the magnetic core memory each cell is bistable, and the information is changed when appropriate signals are applied to the conductors that intersect at the cell. During the times that the panel only stores and displays images an alternating signal is applied across the two grids, and within each grid all conductors are effectively in parallel. Figure 3 shows the appearance of two characters on an 8 x 8 panel. The letters are enlarged about 6 times. Since no select signals were applied when this photograph was taken, the same exciting signal was across every cell in the panel.

In the following two sections we describe the nature of the bistability in the Plasma Display cell, and the mechanisms by which addressing signals change the images on the display.

3. PROPERTIES OF THE SINGLE CELL

An idealized circuit representation of the cell and its surrounding structure is a triplet of capacitors as shown in Figure 2. The outer capacitors represent the capacitances between the outer electrodes and the inner end walls, and the center capacitor represents the capacitance across the end walls of the cell itself. When the voltage across the electrodes is varied, a reduced but proportional variation appears across these end walls. The actual voltage across the walls, which we call the cell voltage, also depends on surface charges deposited on the walls during discharges. We can, then, represent the cell voltage across these walls as the sum of two voltages -- a signal voltage

proportional to the signal at the terminals, and the wall voltage proportional to the surface charges.

When the cell voltage exceeds a critical value, V_f, a gas discharge develops in the cell. The character of the discharge depends on the gas. We have found, for example, that in helium and neon the discharges formed by a 100-500 k.c. signal persist for the greater part of each half period. In nitrogen, on the other hand, the flow of charges to the walls is so rapid that even though the exciting voltage is increasing, the cell voltage is quickly reduced below the firing voltage, and the discharge is extinguished. This entire process lasts about 50×10^{-9} seconds. A mixture of neon and a small percentage of nitrogen retain much of the visual characteristics of neon, but the discharges have the pulse character of nitrogen.

The memory in the Plasma Display cell is provided by the charges which accumulate on the end walls during the pulsed discharges. Although the effect during each discharge is to reduce the voltage across the cell, they provide a voltage which, on the following half cycle, augments the exciting voltage. A sequence of discharges can therefore be sustained by a signal that would be unable to initiate the same sequence. In the voltage range for which this is true, the cell is bistable, and it is capable of storing information. We refer to the signal voltage, when it is in this range, as the sustaining voltage.

The two states are described graphically in Figures 4 and 5 which show both the sustaining voltage and the wall voltage. In Figure 4 the wall charge, and therefore the wall voltage is zero. The peak value of the sustaining voltage is less than the firing voltage and no discharge forms in the cell. This is the "zero" or "off" state. Figure 5 illustrates the

"one" or "on" state. The wall voltage is plotted so that the cell voltage is represented, on the graph, by the distance between the sustaining voltage and the wall voltage. Once each half cycle when the cell voltage equals the firing voltage, the cell fires, and the polarity of the wall voltage changes. This occurs when the sustaining voltage reaches the level marked V_r, which we call the recurrent voltage. The wall voltage is equal to the difference between the firing voltage and the recurrent voltage.

The discharge, as represented by the transitions in the wall voltage curve in Figure 5, functions as an ideal switch, shorting the cell each time it fires, and charging the walls to the recurrent voltage. Although the inertia of the ions causes the wall voltage to change less abruptly, if the final value is V_r, the timing and the character of the next discharge are unchanged. The equality of the wall voltage and the recurrent voltage, however, does indicate the special case of complete wall charging. In this case the cell, once turned "on" will refire for any voltage greater than $V_f/2$. The bistable range then extends from $V_f/2$ to V_f.

If the wall charging were less than complete in Figure 5, the recurrent voltage would increase, while both the wall voltage and the bistable range would decrease. In the limit the wall voltage would be zero, the recurrent voltage would equal the firing voltage, and there would be no memory.

From the character of the memory one might anticipate a problem in changing states quickly enough to be useful. To fire a cell that is "off," for example, the entire firing voltage must be supplied by a signal at the terminals. If the wall then charges to a voltage that is a little less than V_f the cell voltage will again equal the firing voltage early in the next half cycle. The magnitude of the exciting voltage at the first discharge is

greater than it is at the second, and the corresponding wall voltages after these firings will in general, be unequal. In equilibrium, with symmetrical exciting signals, the magnitudes of the recurrent voltages are equal, and the magnitudes of the wall voltages after each discharge are also equal. Without a mechanism for equalizing the wall charging, this transition could not take place.

Fortunately such a mechanism does exist in the form of a relation between wall charging and the slope of the exciting signal. In general the wall charge, and therefore the wall voltage increases as the slope increases. This differential charging mechanism drives the cell rapidly to a condition of equal wall charging, and with symmetrical exciting waveforms, to positions of equal slope. We have observed that with exciting signals in the 100-500 k.c. range this stabilization occurs within one or two cycles. The transition is illustrated in Figure 6. This mechanism not only makes possible rapid access to the Plasma Display Panel, but it makes possible several methods of addressing the display, and a method of directly writing information on the display. We discuss these processes in later sections.

An additional principle underlying the operation of the Plasma Display Panel is imposed by the physics of electrical discharges. Not only must the firing voltage be exceeded in order to establish a discharge, but charged particles must be available to initiate the discharge. When cells in the display are "on," the discharges occur with such regularity, that no jitter is observable even with recurrent sweeps at 50×10^{-9} seconds/division on fast oscilloscopes. We attribute this regularity to the fact that metastable atoms, created during each discharge, diffuse to the walls where they give energy to electrons that are then ejected.

To produce the first discharge in a sequence, however, charged particles must be provided by other means. Since our earliest work with single cells we have stimulated the initial discharges by illuminating the cell with ultra violet light which, in turn, liberates photo electrons at the cell walls. We discovered, in our first work with a 4 x 4 array that any single cell in the "on" state provided enough photo electrons to serve as starting particles for any of the remaining cells. We have made similar observations on an 8 x 8 display. We expect that for larger displays (512 x 512) the panel will be illuminated from behind by an appropriate light source, or by a frame of cells outside the viewing area, but in the plane of the display panel.

4. COMMUNICATING WITH THE DISPLAY

The principal function of the Plasma Display Panel is to display and store digital information generated by the computer. This information can be entered into the display in several ways. Perhaps the most obvious method, and, in fact, the method used first, is to appropriately modulate the amplitude of an alternating signal on selected lines. As implemented with the 4 x 4 array, the amplitudes of sinusoidal signals applied to each line each have one of three levels. The center level is the normal sustaining level. To write a "one" the voltages on the appropriate intersecting lines are raised to the highest level, for which the combination exceeds the firing voltage. After the cell fires they are reduced to the normal sustaining level. Similarly, to write a "zero" the voltages on the appropriate lines are reduced to the lowest level. The net voltage is then insufficient to fire the cell. Returning the voltages to the sustaining level does not refire the cell which

is then in the "zero" state. The voltages across cells in the same row or column as the selected cell change when these signals are applied, but since they remain in the bistable range the states do not change.

Further explanation of the erase process is appropriate, particularly since it emphasizes the importance of differential charging. If the magnitude of the sinusoidal voltage were reduced abruptly after a normal firing, the wall voltage would be left at one of the levels characteristic of the "on" state. The resumption of the normal sustaining level would then initiate a new sequence, and no state change would occur. On the other hand, if the reduction takes place over several cycles, the last firings would occur at points of reduced slope, and the final wall charge would be less than normal. If it were sufficiently small, resumption of the sustain signal would not initiate a new sequence, and the state would have changed from "on" to "off."

Select signals can, of course, be applied to more than one pair of lines simultaneously. In this way an entire line of information can be entered or any rectangular area can be erased at one time.

In a slower but more economical addressing method, slowly varying select signals are added, on appropriate lines, to the sustaining signal which is the same across the entire display. The circuit arrangement is shown in Figure 1. The process of changing states is illustrated in Figure 7 and 8. At the left in Figure 7 the cell is "off" as indicated by the zero wall voltage. During the gap after the sustaining signal is interrupted the write voltage is applied across the selected cell. When the sustaining signal is resumed the combination of the two voltages exceeds the firing voltage and the initial discharge in a sequence is established. The firing points stabilize as described above, and as the write voltage is removed gradually it is tracked

by the wall voltages as shown at the right in Figure 7. As the write voltage is reduced the discharges occur at points of less than normal slope on the positive half cycles and at points of greater than normal slope on the negative half cycles. The charge transferred to the walls is thus less on the positive half cycles than it is on the negative half cycles. It is this differential charging that causes the wall voltage to track the write voltage. After the write voltage has been completely removed the cell remains in the "on" state. Figure 8 illustrates the process of erasing a cell, changing the state of the cell from "one" to "zero." Here the first part of the erase signal is applied before the gap and the wall voltage tracks this signal. We note that the last discharge before the gap actually leaves the wall voltage at zero. During the gap the erase voltage is removed, and when the sustaining signal is resumed the cell remains "off," since the applied voltages are now inadequate to cause a discharge.

With high resistance (0.5×10^6 ohms) in the select lines, the time constant for the select signals is typically 10×10^{-6} seconds, the gap is set to about 40×10^{-6} seconds, and the address cycle is then about 80×10^{-6} seconds. This is fast enough for most information retrieval service, even when cells are addressed one at a time. Of course, since entire lines can be addressed at once, and since any rectangular area can be erased at once, the technique is also suitable for more rapid information transfer.

The display of computer generated images and their interpretation by an observer involves information flow in only one direction -- from computer to display to observer. Interaction between computer and observer, however, requires information flow in the opposite direction. These links are conventionally provided by keysets and light pens, devices that can also be used with the Plasma

Display. In addition, however, the Plasma Display can be interrogated directly by the computer, and information can be written directly on the Display by means of a light emitting pencil. We describe these procedures in the rest of this section.

Since the state of a cell can be detected during the discharge both optically and electrically, it is possible, in two ways, for the computer to interrogate the state of the cell. In one method a photocell is arranged, as shown in Figure 9, to gather light from the entire display. To determine the state of a given cell, the computer interrupts the generator, as it does in slow addressing. It then applies a read signal only to the conductors that intersect at the cell being read. The amplitude of this signal is equal to the sustaining signal, and produces a discharge, or a short sequence of discharges, only if that cell is on. Since it leaves the walls charged to a level appropriate for the "on" state, and since it has no effect at all on a cell in the "off" state, the readout is nondestructive. Half amplitude signals, of course, appear on those cells that have an electrode in common with the cell being read, but these signals are too small to fire the cell. To read an image from the display, therefore, it is only necessary for the computer to scan in sequence, the cells in the appropriate region of the panel.

When a discharge occurs in the cell it can also be detected by means of the current pulse induced in the connecting electrodes. If then a read pulse is applied to one row electrode and all column electrodes, the entire line can be read at one time.

The role of the surface charges in determining the state of a cell suggests that one could write or erase by pointing to selected cells with a light emitting pencil. The procedures, which are similar to those of slow

addressing, are illustrated in Figures 10 and 11. When as shown in Figure 11 the sustaining signal is interrupted, the walls of the cell are left charged. When the light falls on the cell walls during the gap the photoelectrons ejected from the surfaces are drawn to the walls by the electric field. The wall voltage falls to zero, changing the state of the cell from "on" to "off." The write procedure, illustrated in Figure 11 is similar except that a bias voltage is applied at the beginning of the gap before the light is turned on. The photoelectrons are again drawn to the walls neutralizing the electric field. In this case, however, they charge the walls to a non-zero voltage, which remains unchanged after both the write voltage and the bias voltage are removed. Finally, at the end of the gap the wall voltage combines with the sustaining voltage to initiate the sequence of discharges that defines the "on" state.

The erase technique has been demonstrated experimentally, but only for long erase times (20 seconds). The write technique has not yet been demonstrated. Nevertheless, our experience with charge control in slow addressing indicates that the technique will be successful if enough photo electrons are released from the surfaces. With bright light sources or by enhancement of the photoelectric efficiency at the surfaces it should be possible to provide these electrons.

5. STATUS AND PROSPECTS

The soundness of the Plasma Display Principle has been demonstrated at the University of Illinois, and it has been confirmed by work at other laboratories. The principal development goal now is the realization of a large (512 x 512) array for information display. This involves study of

materials, fabrication methods, and circuits, along with a continuing study of the physics of electrical discharges in insulated gas cells. At Illinois we have, so far, conducted our experiments with arrays no larger than 16 x 16. Efforts to fabricate larger displays are being made and a number of panels with 132 x 132 arrays have already been constructed[4] by Mayer.

Beyond this goal, interest is developing in extensions of the display technique to include color and grey scale. It seemed likely from the earliest experiments that the use of phosphors inside the cells could be used in multi-color displays. The later observation of ultra-violet radiation in the cells led to the idea that this radiation could excite phosphors deposited on the outside of the outer glass panels, and that the effect should be enhanced if the panels were made of quartz or some other material with good U V transmission characteristics. Experimental confirmation of these ideas has recently been made by Morrison, Markin, and Sobel.[5]

The achievement of variable intensity imposes no problems if one is willing to increase the number of cells. For example, if the number of conductors is doubled, each cell is replaced by a display unit of four cells. With suitable masking 16 levels of intensity are provided. Other techniques using only one cell are being investigated.

Applications of the Plasma Display principle have also become apparent in such diverse areas as high speed printing, computer memories, and nuclear physics instrumentation.

ACKNOWLEDGEMENTS

The work on which this paper is based could not be accomplished without the cooperation and assistance of many members of the staff of the Coordinated Science Laboratory. For this we are deeply appreciative. In particular we are indebted to R. Johnson, R. Trogdon, J. Knoke and N. Vassos for their technical contributions, and to D. Alpert, D. Lee, and F. Propst for their consultation.

REFERENCES

1. Bitzer, D. L., Slottow, H. G. and Willson, R. H., "A Preliminary Description of the C.S.L. Plasma Display," Internal Report - Coordinated Science Laboratory, Univ. of Ill., Urbana, Ill., Nov. 1965.

2. Willson, R. H., "A Capacitively Coupled Bistable Gas Discharge Cell for Computer Controlled Displays," Report R-303, Coordinated Science Laboratory, Univ. of Ill., June 1966.

3. Bitzer, D. L. and Slottow, H. G., "The Plasma Display Panel -- A Digitally Addressable Display with Inherent Memory." Proceedings of the Fall Joint Computer Conference, San Francisco, California, Nov. 1966.

4. Mayer, W. N., private communication, 1967.

5. Morrison, J., Sobel, A., and Marken, J., private communication, 1967.

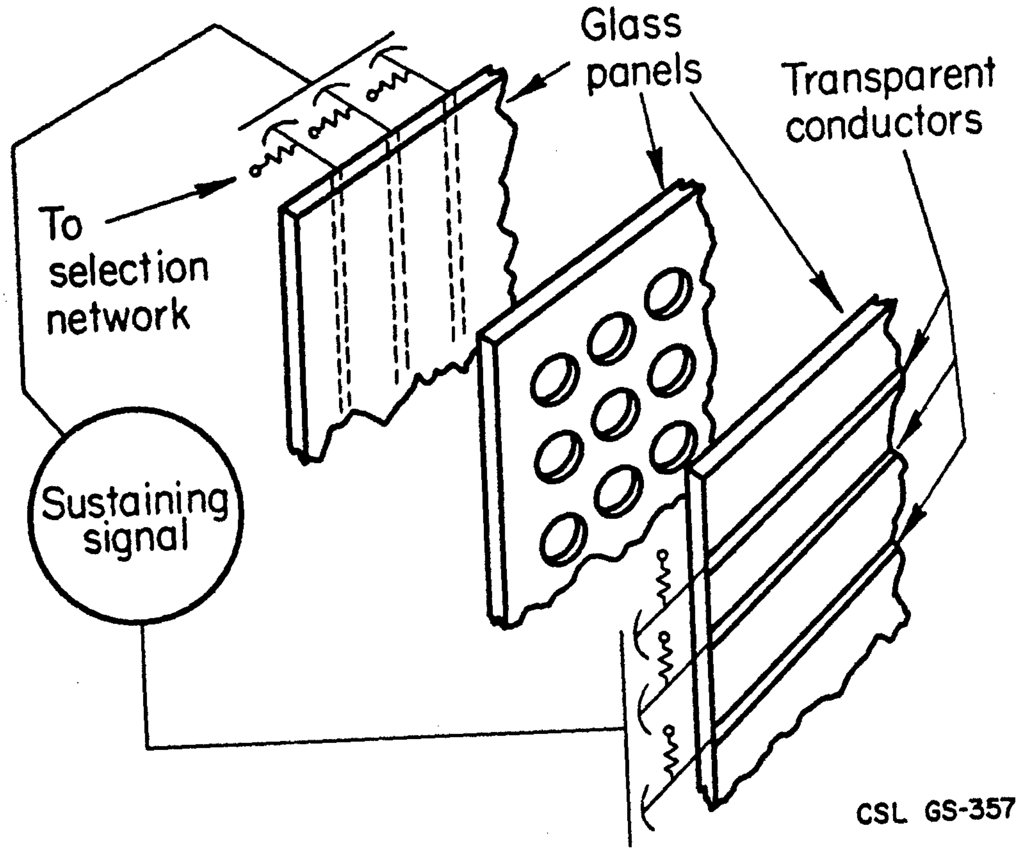

Figure 1. Assembly of Plasma Display Panel

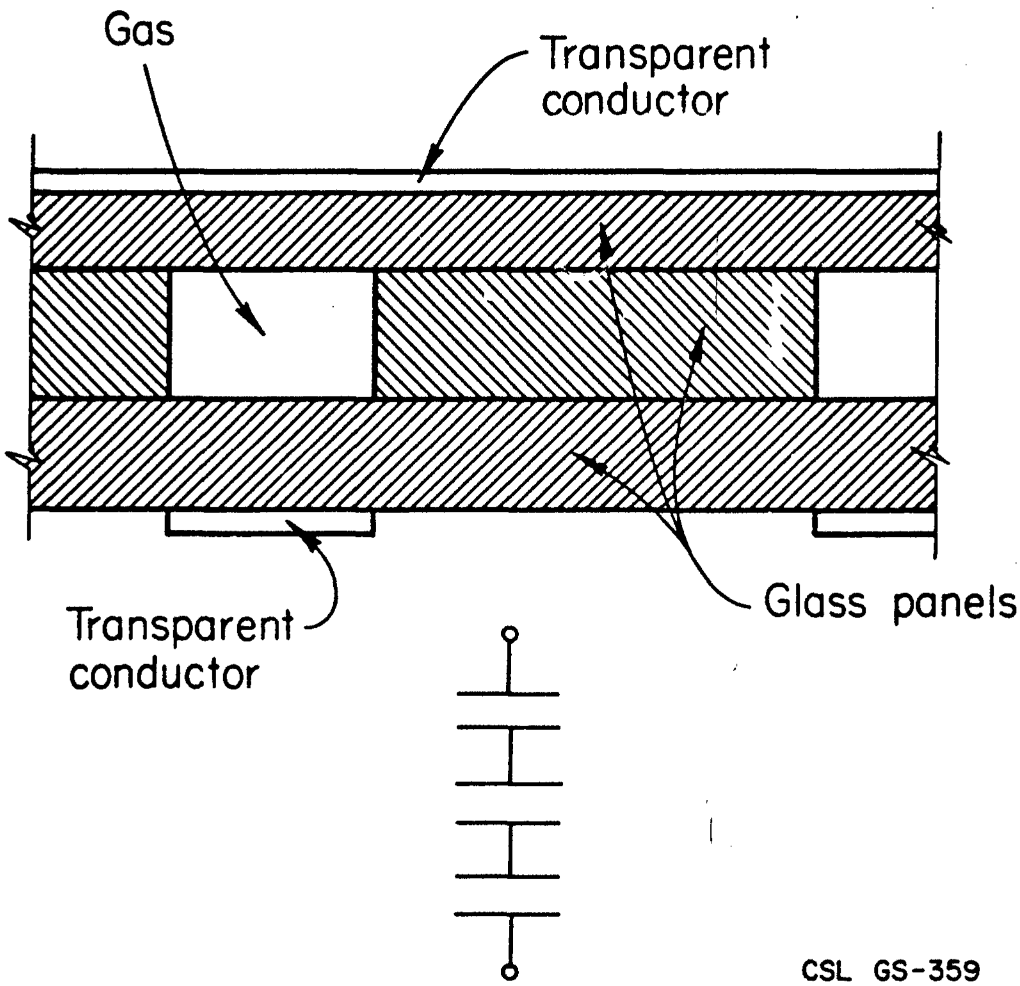

Figure 2. Gas Discharge Cell and Idealized Circuit

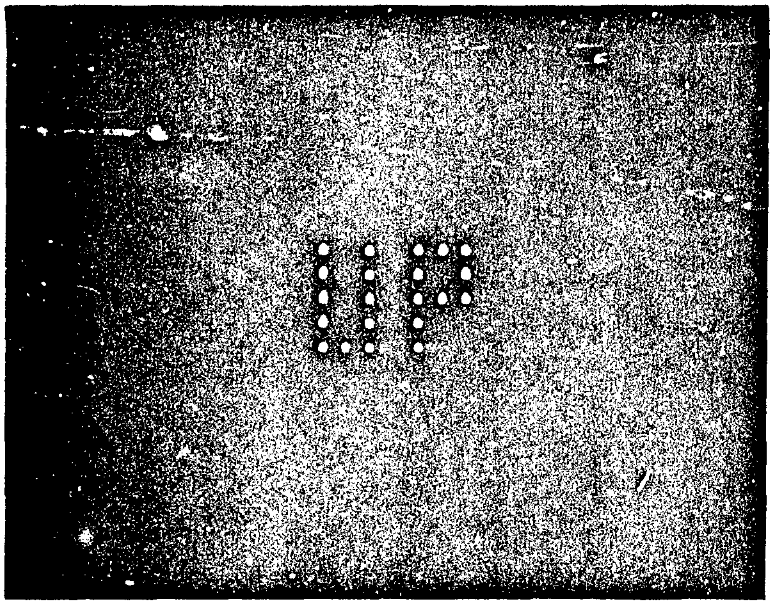

Figure 3. Appearance of Characters on 8 x 8 Plasma Display Panel

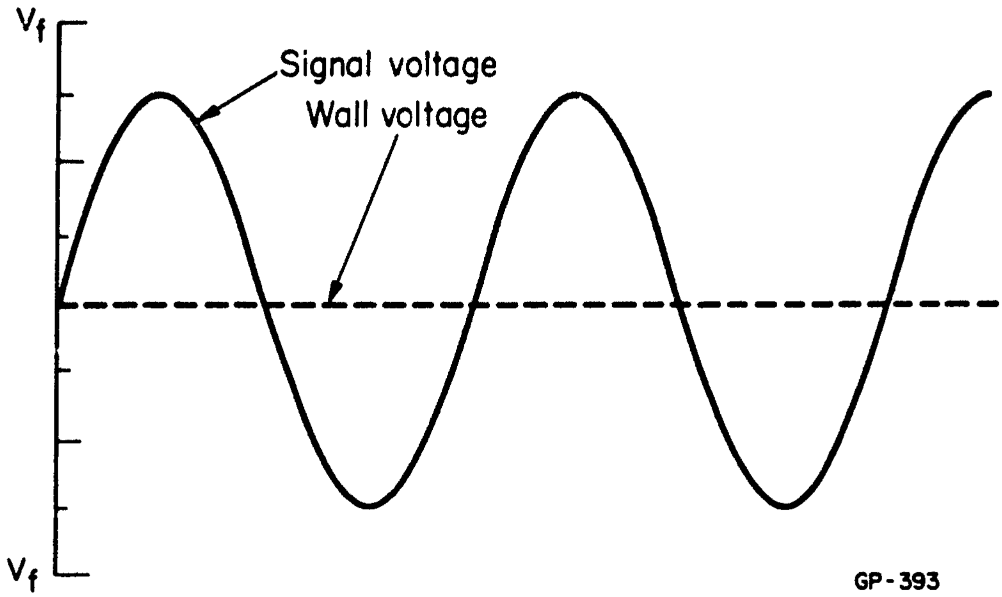

Figure 4. Cell Voltages for "OFF" State

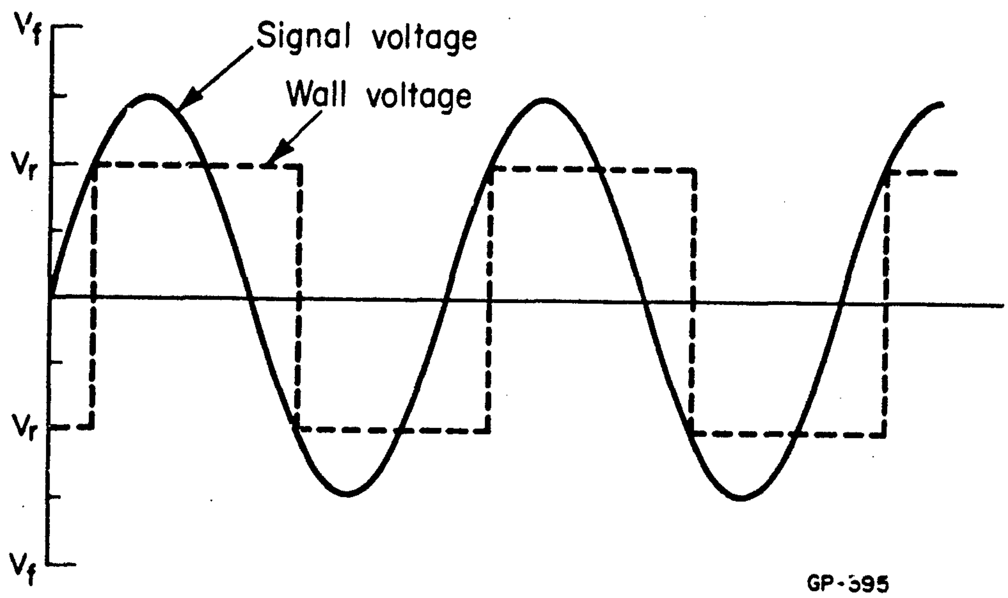

Figure 5. Cell Voltages for "ON" State

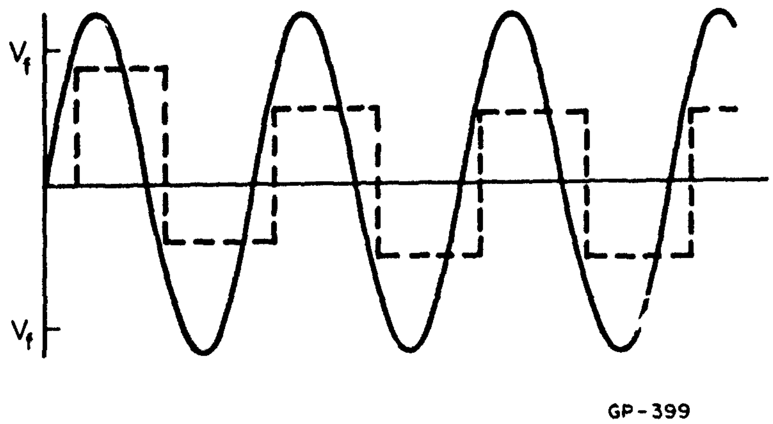

Figure 6. Transition to "ON" State

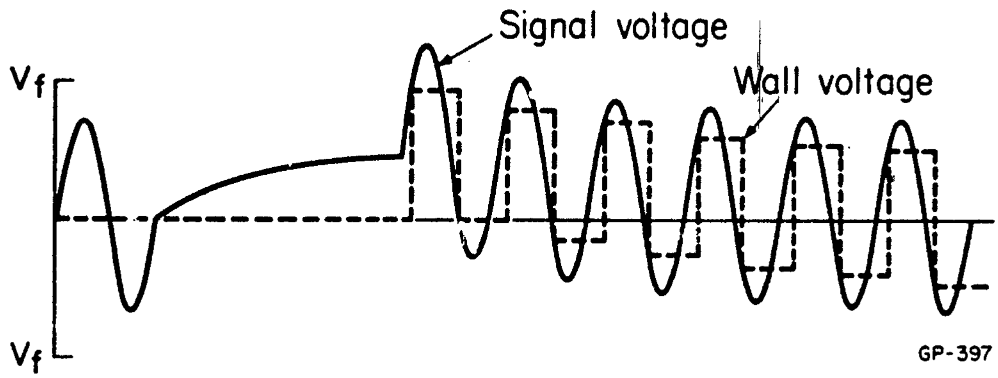

Figure 7. Slow Write

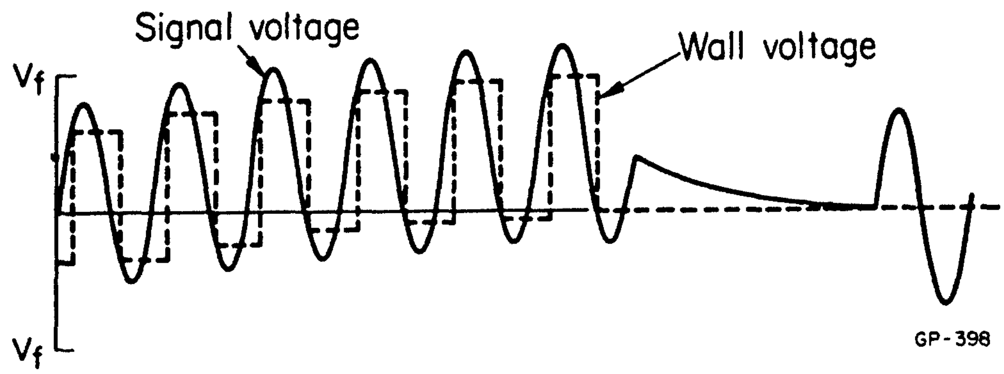

Figure 8. Slow Erase

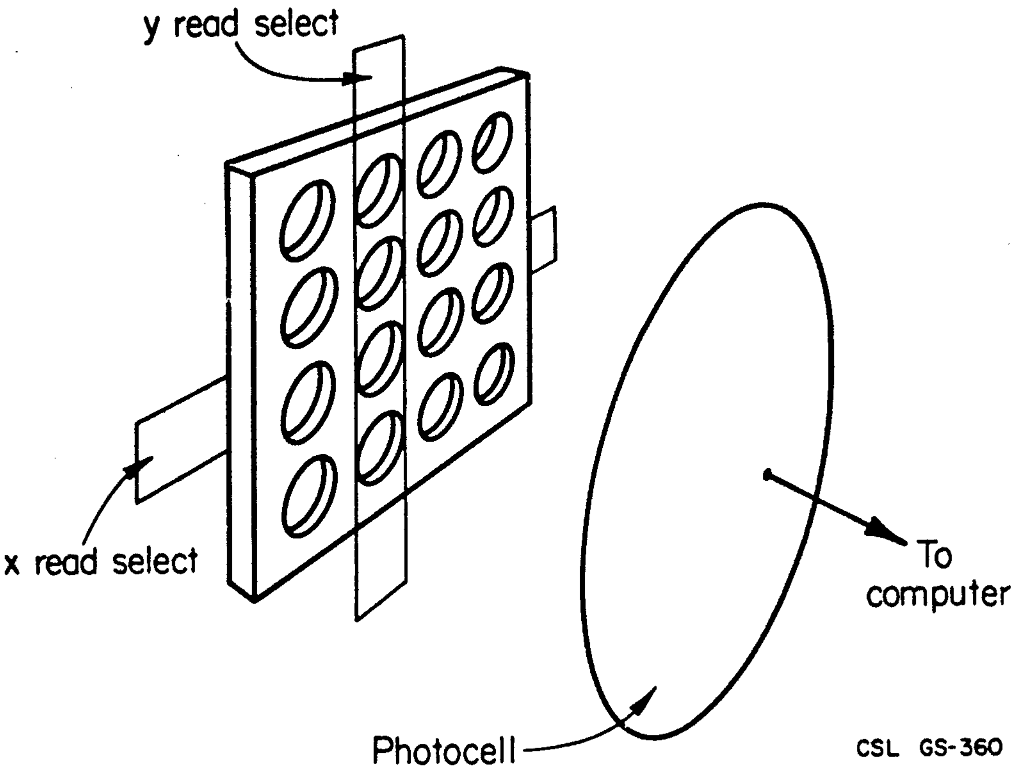

Figure 9. Interrogation of Display Panel By Computer

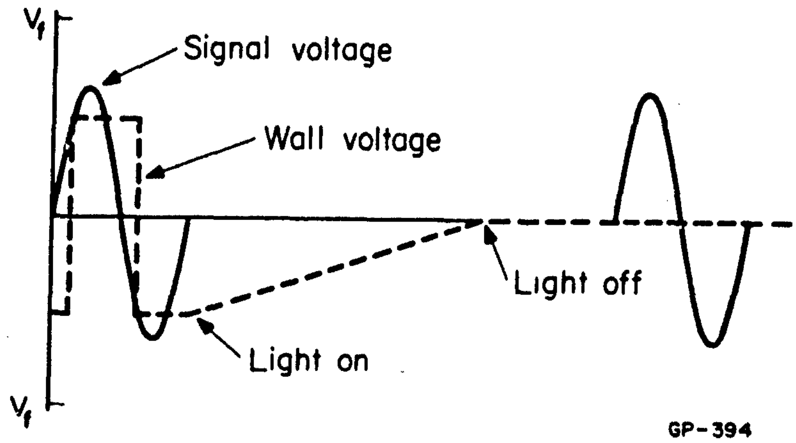

Figure 10. Cell Voltages for Light Pencil Erasing

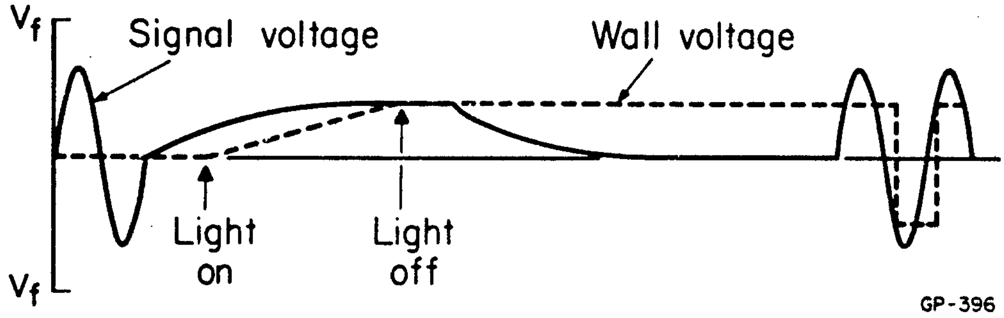

Figure 11. Cell Voltages for Light Pencil Writing

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) University of Illinois Coordinated Science Laboratory Urbana, Illinois 61801	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

THE PLASMA DISPLAY PANEL--A NEW DEVICE FOR INFORMATION DISPLAY AND STORAGE

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

ARORA, B. M.; BITZER, D. L.; SLOTTOW, H. G.; WILLSON, R. H.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April, 1967	24	5

8a. CONTRACT OR GRANT NO. DA 28 043 AMC 00073(E) 20014501B31F: b. PROJECT NO. also in part Syracuse Univ. Res. Corp. SURC 66124; ONR c. Nonr-3985(08). d.	9a. ORIGINATOR'S REPORT NUMBER(S) R-346 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

DISTRIBUTION OF THIS REPORT IS UNLIMITED.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Joint Services Electronics Program thru U.S. Army Electronics Command Fort Monmouth, New Jersey 07703

13. ABSTRACT

The Plasma Display Panel, invented at the University of Illinois, is a rectangular array of bistable gas discharge cells which are insulated from exciting electrodes by thin glass panels. Combining the properties of memory, display, and high brightness in a simple structure it is an effective, economical device for information display.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

Security Classification

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
DISPLAYS						
COMPUTERS						
INFORMATION DISPLAY						
MEMORIES						
PLASMA DISPLAY						

DD FORM 1 NOV 65 1473 (BACK)

S/N [illegible]

Security Classification

A-31A